Wear Behavior of CoCrMo Alloys for Metal-on-Metal Hip Joints

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論文内容要約

CoCrMo alloy has been used in hip prosthesis manufacturing since 1930 as it is very durable and biocompatible. However, recent studies also indicated unexpected high failure rates and a large quantity of debris for large head metal-on-metal (MOM) bearings, which led to an alert from the Medicines and Healthcare products Regulatory Agency prompting an urgent review of all MOM articulations. The key factors to affect the wear behavior of the MOM bearings mainly include: (1) the microstructure of the material (the use of high carbon (HL) or low carbon (LC) alloy with various processing or heat treatments), (2) macro- and micro-geometry (difference in diameter and the radial clearance between mated components), (3) the resultant type and amount of lubrication.

In this study, the wear behavior of various biomedical CoCrMo alloys has been investigated under different experiment conditions (wear test by pin-on-disc and hip joint simulator), for an elucidation of the separate and synergy influence coming from these key factors.

Firstly, the microstructures effect of the alloys on the wear behavior was evaluated with forged and hot-pressed CoCrMo alloys with different carbon contents, by performing pin-on-disc wear tests. The results indicated that despite of various processing methods, for γ-phase matrix, inhomogeneous precipitates (σ or carbides) were the main reason to lead to two-body abrasion in grain basin; particulate σ in carbide interface is detrimental to cause micro cracks for HC alloys; ε-phased alloy with homogeneous $M_{23}C_6$ and M_2N exhibits better wear resistance.

Then geometrical effect of the MOM bearings on the contact mechanics and wear behavior was evaluated with LC forged CoCrMo alloy by performing wear tests in a hip joint simulator. The results by finite element simulation indicated that as radial clearance decreases and head diameter increases, the MOM bearings exhibit better contact status, which resembled the results of the actual experiment. Since the contact during a gait is discontinuous, sliding and pitting zones were observed on the worn surface, beneath which similar subsurface micro-structural changes characterized as nano crystal layer, strain-induced martensite, and matrix were observed.

Finally, the microstructures effect of HC and LC alloys with different combinations (LC-LC, HC-HC, LC-HC and HC-LC) was evaluated by performing wear tests in a hip joint simulator, under fetal bovine serum environment. The HC-HC combination showed lowest wear rate, however, no significant difference is between any two wear groups ($p > 0.05$). Abrasion and surface fatigue were the dominant wear mechanisms for LC and HC alloys, respectively. Micro crack on the LC component was a significant reason for the unstable MOM wear rate of LC-HC bearings. Lubrication is more significant than carbon content affecting wear behavior of MOM bearings, since significant difference is observed between volume loss of LC-LC bearings lubricated in bovine and Hanks enviroment ($p > 0.05$).